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A STUDY ON THE EFFECT OF MAGNETIC FIELD ON THE PROPERTIES AND COMBUSTION OF HYDROCARBON FUELS

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ABSTRACT

Researchers all around the world are working towards possible solutions to the problems of accelerating depletion of fossil fuels, and the perennial problem of pollution associated with the combustion of such fuels. Towards the end of twentieth century, the effect of strong magnetic fields on molecular structure and its potential to alter the properties at the molecular level were discovered. A number of researchers have focused their attention on this topic, and have come out with appreciable results regarding the performance and exhaust emission characteristics of magnetically conditioned hydrocarbon fuels. In this paper, a comprehensive review has made on the effect that magnetic fields create on the structure and properties of hydrocarbons, and the effect it produces on the combustion and emission characteristics of magnetically conditioned hydrocarbon fuels.

KEYWORDS: Fossil Fuels, Hydrocarbon Fuels, Combustion & Emission

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INTRODUCTION

The world is facing an acute shortage of energy from fossil fuels. The dependence on fossil fuels and the pressure on existing non-renewable energy sources are so high that they would get depleted in the near future. The energy requirements of human beings have increased manifold, owing to the exponential growth of population; and the gap between supply and demand of energy is increasing at an alarming rate.

Another global trans-boundary problem associated with the fossil fuels is the ever-increasing rate of environmental pollution. Statistics show that there has been a 50% increase in annual global emissions from fossil fuels in a time of 20 years ranging from 1990 to 2010. The pollutants emitted during fossil fuel combustion include CO, CO_2, Oxides of nitrogen, Oxides of sulphur, UBHC, lead and suspended PM. These pollutants have damaging effects on both living and non-living components of the ecosystem.

The anticipated depletion of the fossil fuels in the near future and the adverse effects of emitted pollutants have made the researchers around the world to think about different methods of conditioning the fuels, that will increase their combustion efficiencies and bring down the resultant pollutants. One such method is the magnetic conditioning of fuels.

THEORY OF MAGNETIC FUEL CONDITIONING

Any hydrocarbon fuel is a compound of molecules. These molecules consist of a number of atoms, which in turn made up of nucleus and electrons. Thus, it is quite clear that both positive and negative electrical charges exist in the molecules. These molecules in their natural state form a cluster within them, and will not actively

interlock with the oxygen molecules during combustion. Hydrocarbons can be polarised by the exposure to external magnetic fields. The effect of such magnetism is the creation of a moment caused by the movement of outer electrons of a hydrocarbon chain, moving the electrons into states of higher principal quantum number. This state effectively breaks down the fixed valence electrons that part take in the bonding process of fuel compounds. The hydrocarbons become directionalised and align the conduced magnetic moment into a dipole relationship within itself. On the application of a magnetic field, the hydrocarbon molecules of a fuel are ionized and realigned, resulting in the weakening of Vander Vaal's bonds followed by the de-clustering of existing hydrocarbon clusters. Subsequently, this will result in the active interlocking between fuel and oxygen molecules, ensuring better completion of combustion process.

In the process of combustion of a hydrocarbon fuel, it is the outer shell of hydrogen that gets combusted first. Hydrogen exists in two distinctive forms- ortho hydrogen and para hydrogen. The ortho and the para variants of hydrogen differ in the relative orientation of nuclear spin of the two protons. In the para state, spin of the protons is anti-parallel, whereas in the ortho molecule, the spin is parallel. This spin orientation has a pronounced effect on the behaviour of the molecule. Ortho hydrogen is found to be unstable and more reactive than para state. The fuel molecules will normally be in the para state with opposite spins, getting attracted to each other, forming clusters. When the fuel is mixed with air at that particular condition, all the molecules of the fuel may not combine with the oxygen molecules in the air for combustion, and hence some of the fuel molecules escape into the atmosphere as unburnt gas. When magnetic treatment is carried out, the molecules that normally occur in the para state gets oriented into the active ortho state, thus weakening the bonds between fuel molecules.

Faraday's law states that when a field is introduced perpendicular to that circuit, electro-motive force acts upon the electron, by which the nature of motion of atomic orbits is altered. Hence, a diamagnetic ion subjected to magnetism exhibits positive ionization, which in turn helps the hydrocarbons to attract and bond with negatively charged oxygen.

From the thermodynamic point of view, the consumption of fuel is completely dependent on its combustion enthalpy. The enthalpy of a reaction can be calculated by using the bonding energy of reactants and products. If the magnetic treatment is able to alter the bonding energy of hydrocarbon molecules, the consumption rate of fuel will get altered as well. Thus, the reduction in the bonding energy directly affects the enthalpy and subsequently affects the rate of consumption of fuel. The weakening of bonds between fuel molecules also aid in the formation of more bonds with oxygen molecules, ensuring an increase in combustion efficiency.

EFFECT OF MAGNETIC FIELDS ON HYDROCARBON STRUCTURE, PROPERTIES & FLAME BEHAVIOUR

Shoogo Ueno [1] studied the effect of magnetic fields on the structure of flames and gas flows under external combustion using methane, propane and hydrogen as test gases. He observed that the shapes of the flames were drastically changed by the magnetic field, independent of the gases used. The combustion velocity was also found to increase in proportion to the gradient of the field. In another study [2], they observed that combustion velocities and temperatures are influenced by magnetic fields.

Guo et. al.[3] proposed the effects of magnetic field on the physio-chemical properties of individual hydrocarbons. They observed a fractional change in viscosity of hydrocarbon fuel on the application of a magnetic field. The magnitude of viscosity change was found to be increasing with increasing strength of the magnetic field.

The more the carbon numbers of the normal paraffinic hydrocarbons, the more rate of decrease of viscosity was observed. Their study showed that surface tension of hydrocarbons also decreased marginally upon magnetisation. An unpremixed diffusion flame of butane was exposed to a negative gradient magnetic field by Aoki [4]that resulted in the increase in temperatures, reduction of dimensions and an increase in the bluing tendency of the flame

Wakayama [5] observed that a combustion reaction is initiated when a fuel gas is made to flow in a downward gradient magnetic field. His investigation on methane diffusion flames proved that a negative gradient field increased the combustion rates for diffusion flames whereas the field had little effect on premixed flames. He also suggested that a gradient magnetic field could control a chemical reaction in which the magnetic susceptibilities of individual species are involved. Baker and Varagani [6] examined laminar diffusion slot flames under non-uniform magnetic fields. Slot flames were chosen for the study because of the simplicity of obtaining a symmetric magnetic field around them during mathematical modelling. They observed a decrease in maximum flame temperature with the application of an upward decreasing magnetic field. The potential of a constant magnetic field in altering the propagation conditions of a combustion wave was studied by Morozov et. al. [7]. They observed an increase of combustion velocity by 30% in a 0.27T magnetic field. This increase in combustion velocity is attributed to the degree of agglomeration of the system in a magnetic field. A combustion electromotive force is developed owing to the ionisation of the reagents and intermediate products in the combustion front.

A strong pulse magnetic field with suitable duration was applied in the investigation of Tao [8], which was found to reduce the viscosity of gasoline and diesel. The viscosity reduction was only for some hours and the original property values were regained after some time. In another study, Tao & Xu [9] investigated the relationship between applied magnetic field and viscosity of an MR fluid and crude oil, the optimum duration of magnetic field application and the average size of particle clusters when duration of applied magnetic field is increased. It is evident that the Paraffin particles have different magnetic permeability from the solvent, which resulted in viscosity reduction. The effect of a magnetic field on the structural and rheological properties of crude oils with various concentrations of resins, asphaltenes, and paraffin hydrocarbons was examined by Loskutova et. al. [10]. It was found that in high viscosity oils, the characteristics such as viscosity, antioxidant and paramagnetic properties are affected when subjected to magnetisation. The time of complete recovery of paramagnetic and antioxidant properties coincides with the recovery time of the rheological characteristics of petroleum.

Evdokimov & Kornishin [11] carried out a critical study to disprove the earlier published physics of viscosity reduction due to magnetic fuel conditioning. They concluded that the viscosity reduction due to MFC occurs due to disaggregation of colloids in the oil. The effect of a high downward decreasing magnetic density on a laminar methane diffusion flame was studied by Legros et. al. [12]. A flickering of flame was observed in their study with downward gradient magnetic flux ranging from 0.4 to 1.4 T^2/m. They also suggested that buoyancy and shear stress might be strengthened by the magnetic force, thus hastening the instability onset. Gillion et. al. [13] Conducted experiments on a burner to which propane is issued vertically through an open cylindrical cavity, which is placed inside the air gap of an axisymmetric superconducting magnet. The interaction of magnetic field on combustion was explained based on three mechanisms-Lorentz force, direct effect on chemical reactions and indirect effect on oxygen.

Ciabanu et. al. [14] designed and built a magnetic system, which can be at upstream of a burner. The dimensions and shape of the system was determined based on earlier simulations. Their magnetic circuit had a special

geometry that can create an even magnetic field throughout the width of the pipe. The potential of an electromagnetic field in improving the efficiency of a diesel engine was studied by Uguru-Okorie and Dare [15]. Their review conclude that the reduction in viscosity obtained through magnetisation results in reduced Sauter Mean Diameter of fuel droplets, which in turn results in better atomisation and combustion of the fuel. Attar et. al. [16] observed that the time taken for a hydrocarbon fuel to get collected in a flask with magnetic field reduced as the field strength applied to the flow line was increased. This can be taken down as an evidence of decrease in fuel viscosity with increase in the magnetic field. The effect of magnetic field on fuel properties was studied by Ugare et. al. [17], whose findings include a reduction in density up to 1.25% and an increase in calorific value by 1.19% when gasoline was used as the test fuel. This effect is accounted on the change in orientation of hydrocarbons from para to ortho state under the influence of strong magnetic fields.

The effect of magnetisation on n-hexane and benzene in molecular and electronic scale was investigated by Jalali et. al. [18]. Their tests using UV-visible and FT-IR techniques suggested that Frank-Condon factor (FC), which is a measure of vibrational states of molecules, is affected by magnetisation. On exposure to strong magnetic fields, the hydrocarbon molecules got modified by activating new vibrational modes. This resulted in increased kinetic energy and free energy of fuel, thereby increasing the combustion enthalpy. Kumar & Shakher [19] conducted experiments on premixed, partially premixed and diffusion flames generated by butane torch burner in the absence of magnetic field and in the presence of uniform and non-uniform magnetic fields. They studied dimensionless parameters like magnetic Grashoff number, magnetic Froude number and Reynolds number to find out how butane fames are affected in the presence of a magnetic field. It is evident from their results that oxygen concentration is reduced because of dominance of momentum force on butane gas.

Agarwal et. al. [20] made use of a Tablot interferometer to study the impact caused by magnetisation on the temperature profile of a diffusion flame. They observed that an upward increasing magnetic field resulted in the decrease in flame temperature and vice versa. Their study also proved that very little or no effect is produced on the temperature of a flame by a uniform magnetic field. The Effect of magnetic field on physical properties and Cetane number of diesel fuel was investigated by Elamin et. al. [21]. Density and viscosity reduced on magnetisation because some of the branched and ring compounds are converted to linear hydrocarbon chains. In addition, they observed an increase in Cetane number of diesel from 56.6 to 60.3, which indicates that the quality of fuel was improved. The interaction of magnetic fields with combustion was studied through various dimensionless numbers by Singh[22]. He studied Froude number, Grashoff number and Reynolds number and assessed that flame behaviour is affected by magnetic fields. An experimental investigation of properties of methane laminar combustion under strong magnetic fields was conducted by Wein-Fei Wu et. al. [23]. In this natural gas fuelled test, they observed that an increasing gradient field intensity in the vertical direction resulted in an increase of flame temperature by 52 K on an average.

An experimental study of combustion of wood biomass using the propane co-fire and swirl-induced stabilization of the flame reaction zone was carried out by Barmina et. al. [24]. They concluded that the field-enhanced mixing of the flame compounds and combustion of the volatiles promotes a radial expansion of the flame reaction zone, decreasing CO and H_2mass concentration and increasing the CO_2 and NOx volume concentration and total amount of produced heat. Their results have shown that the magnetic force, acting on the flame flow enhances the mass transfer of paramagnetic oxygen in a field direction to the surface of burning wood fuel by enhancing recirculation with the reverse axial flow

formation and more intensive mixing of the flame compounds. The variations induced on flame velocity, composition, temperature and combustion efficiency profiles by a magnetic field were experimentally studied by Barmina and Zake [25]. Their results show that the enhanced mass transfer due to magnetism significantly disturbs the axial and tangential velocity and composition profiles. Thus, combustion reactions get enhanced along the outside part of the reaction zone.

EFFECT ON PERFORMANCE & EMISSIONS OF ENGINES FUELLED BY MAGNETICALLY CONDITIONED HYDROCARBONS

In 1992, Stamps et. al. [26] patented a device containing a permanent magnet assembly having at least one magnet placed adjacent to the fluid passageway. Two magnets were placed diametrically opposed in relation to the fluid passageway and the magnetic conditioning device was tested on a six cylinder 3.3 litre fuel injected Plymouth Voyager engine. The mileage improved by 2.3 miles per gallon. The time required for heating a fixed quantity of kerosene was taken as a parameter for the calculation of thermal efficiency by Saksono [27]. Magnetic intensity, pole orientation, fuel flow rate and distance of magnet from burner were varied for examining the effects. From his research, it is evident that magnetisation can increase the efficiency of kerosene stove, the maximum improvement being 17.5%. It can also be concluded that distance at which magnet is placed also has a profound effect on efficiency improvement.

NdFeB magnets of varying intensities were placed with their north poles facing the radiator core on a single cylinder two-stroke spark ignition engine by Govindasamy et. al [28]. Brake Thermal Efficiency and peak pressure of the engine increased by 3.2% and 6.1% respectively together with a reduction of unburnt hydrocarbons and Carbon monoxide. In another work [29], they applied monopole technology and deduced that peak pressure increases for each cycle as the magnetic strength was increased. Govindasamy& Dandapani [30] tested the magnetic conditioning of Jatropha Biodiesel on a single cylinder four-stroke diesel engine. Thermal Efficiency increased up to 5% and emission of NO_x became near zero. Different stages of tests were carried out on a 6 cylinder 4S Perkins marine diesel engine by Clifford et. al. [31], which yielded a reduction of specific fuel consumption up to 3.26%. A reduction of SFC by 15% together with a decrease in emission concentration of CO, HC and NO_x was obtained by Fatih et. al. [32] when permanent magnets were used on a four-cylinder four-stroke petrol engine. Copper wound electromagnets were mounted on a single cylinder, four-stroke Imex engine by Okoronkwo et. al. [33]. Their research yielded a reduction of UBHC by 50% and carbon monoxide by almost 35%.

The performance and emissions of a single cylinder four-stroke VCR petrol engine was investigated with ignition timing varying between 5 degree and 30 degree bTDC in steps of 5 degrees each by Habbo et. al. [34] using magnetic coils of 1000G and 2000G. Considerable decrease in specific fuel consumption and a significant decrease in exhaust were noted. There was also a fall in exhaust gas temperature up to 8%. Faris et. al. [35] investigated the effect of magnetic field on microstructure of fuel using spectrums. The tests were extended on to a two-stroke spark ignition engine, in which specific fuel consumption showed a reduction up to 14%. Emission of UBHC and CO decreased up to 30% and 40% respectively, but an increase in 10% was noted in carbon dioxide emission.

Both the fuel and airlines of a single cylinder, vertical diesel engine were magnetised using permanent magnets by Jain et. al. [36]. They observed that maximum reduction in fuel consumption was at highest loads when the load is varied from 0 to 10-kg. Two electromagnetic fuel savers with cores made up of plain carbon steel and copper were developed by Siregar and Nainggolan [37] and tested both in laboratory and on road conditions. Copper core was found more effective in inducing magnetic force than steel, though theory proposes the opposite case. Attor et. al. [38] conducted tests on a

stationary diesel engine as well as on board a motor bike with applied magnetic intensities varying from 2000G to 8000G. The mileage of the bike was found to increase about 7kmpl in the on board tests. A major contradiction to the existing results was presented by Ugare et. al. [39] in the case of NO_x emissions. In their tests using magnetic field value of 5000G, NOx was found to increase by 19%. They observed an increase of 1.19% in the calorific value of petrol through magnetic conditioning, but the underlying physics of the phenomenon has not been discussed.

A set of on board experiments were carried on various automobile brands fuelled with magnetically conditioned gasoline by Garg et. al. [40]. All brands showed an improvement in performance and emission characteristics, though the percentage of improvement varied depending on the make of the engine. On an average, mileage increased by 15 to 25%. An increase of 2% in brake thermal efficiency with a reduction of 27% in NOx emissions was obtained by Patel et. al. [41] using ferrite magnets of varying intensities. Vijayakumar et. al. [42] used NdFeB magnets of 6000G coated with Ni-Cu-Ni on a single cylinder four-stroke diesel engine. AFR was found to change from 31.38 to 33.8 with a noticeable improvement in performance and emission characteristics.

Patel et. al. [43] made investigations on a diesel engine with the application of magnetic conditioning alongside catalytic convertor. Maximum improvement in performance and emission characteristics was obtained by the combination of both technologies. The amount of CO_2 and O_2 in the exhaust increased with these modifications. Sala & Notti [44] installed an electromagnetic device on board a fishing vessel. An overall reduction of 4.6% was observed in fuel consumption after the installation of magnetic device. CO reduced by 14.1%, but CO_2 increased by 11.4%. An inspection proved that the injectors of the vessel that used the magnetic device were in a cleaner and better condition. Abdel-Rehim et. al. [45] conducted a series of experiments to explore the effect of magnetic fuel treatment on the performance of combustion engines. Gasoline, diesel and natural gas were tested in two different engines with different configurations under the exposure of magnetic field. Their study concluded that the highest impact of magnetisation was on gasoline fuel compared to the other two fuels.

Kana & Shaija [46] mounted a solenoid electromagnet on the fuel line of a single cylinder diesel engine. Brake thermal efficiency was found to increase by at least 5% and NOx emissions reduced by almost 44% in the process. Similar experimental set up and procedure was employed by Chaware et. al. [47] and found an improvement in thermal efficiency of the engine up to 14% while reducing UBHC by 34%, CO and CO_2 by 9% each. Exhaust gas temperature was found to increase with increase in magnetic intensity. Experiments were carried out on board motor cycle engines by Saxena [48] to study the effect produced by magnetisation. Notable reduction in HC and CO emissions was obtained in their work.

Jundale &Patil [49] applied NdFeB magnets on a four-cylinder, four stroke Premier Padmini engine running at a constant speed and observed a reduction of carbon monoxide emissions by 52%, UBHC by almost 14% and NO_x by 11%. Khedawan & Gaikwad [50] studied the effect of magnetic fields on hydrocarbon-based refrigerant R600 and non-hydrocarbon based R134A for a vapour compression system. Fuel consumption and exhaust concentration reduced for hydrocarbon based R600 upon magnetic conditioning. There was no effect for the magnetic field on non-hydrocarbon based refrigerants. A Mercedes Benz engine fuelled by Iraqi gasoline was magnetised and put under study by Mohammed Al-Rawaf [51]. A reduction of fuel consumption by 5.5% and an increase in brake thermal efficiency up to 13.5% was obtained in this work. Gabina et. al. [52] studied the utility of magnetic devices in increasing the energy efficiency of fishing vessels. They tested three independent magnetic devices on three different compression ignition engines under different operating conditions. Fuel consumption was found to decrease at larger loads in laboratory conditions.

A notable reduction in CO emissions at lower engine speeds was also observed.

Gad [53] conducted experiments on a single cylinder, four-stroke kirloskar diesel engine only at full load and no load conditions. SFC reduced by 3% to 8.5% from no load to full load. CO emission reduced by 10% and 4.5% whereas NO_x reduced by 13% and 24% respectively. The impact on the performance and emissions of a diesel generator when a magnetic tube is included in the fuel intake was investigated by Chen et. al. [54]. A decrease in specific fuel consumption of 3.5% and an increase of brake thermal efficiency by the same magnitude was observed in their experiments. Kurji and Imran [55] conducted tests on a single cylinder four-stroke CI engine with permanent magnets installed before the injection pump. Fuel consumption reduced up to 15.71% owing to reduced surface tension due to magnetisation. The emissions like CO, HC and NO_x also reduced significantly.

CONCLUSIONS

Various works on the effect of magnetic field on hydrocarbon structure, properties, flame behaviour and the effect it produces on the performance and emission characteristics of different types of Internal Combustion engines is comprehensively reviewed. The study shows that a significant improvement is possible in the properties of hydrocarbon fuels up on magnetic treatment. The applied magnetic field, if strong enough, can press back and interfere with the normal flame behaviours. Majority of the research works prove that the performance parameters of an engine like specific fuel consumption and Brake Thermal Efficiency can be improved to a significant level, whereas some works reflect contradicting results in the case of emissions of pollutants like CO_2, NO_x etc. Extensive research in this area can eliminate the existing confusions and explore the implementation of this technique on board automobiles and stationary engines, which can help in minimisation of pollution and fossil fuel utilisation in the future.

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